UNIVERSITY OF TWENTE.

Philosophy of Engineering: Science

Lecture 3A: Scientific Reasoning and Methodology: Hypothetical Deductive method

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I. Epistemology (16th-7th century)

They asked: What is the basis (solid ground) of knowledge? How can we be certain?

Rationalism	Empiricism
	
Rene Descartes	**Francis Bacon**

Rationalism: First principles (such as those in logic and mathematics) are intuitively certain. They cannot be denied. Furthermore, we may trust that God does not deceive us. All other true knowledge must be derived (deductively) from first principles.

Empiricism: All true knowledge must be acquired by means of observation. Correspondece theory of truth: Knowledge **corresponds** with the world.

Epistemology: Scientific method

Rationalism	Empiricism
Science starts with finding first principles (axioms) ⇒True knowledge by means of deduction from first principles	Science starts with observation ⇒ True knowledge by means of induction ⇒ Laws of nature

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Is it possible to prove scientific knowledge?

Same question as last week, but possibly your opinion has changed:

1. Is it possible to prove scientific knowledge? Yes = True; No = False
2. If YES (it is possible to prove scientific knowledge: How? If NO (it is not possible to prove scientific knowledge): Why not?

What is Scientific Method?

Feynman explains “How we find a new law”

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https://www.youtube.com/watch?v=EYPapE-3FRw

What does Feynman say about science and scientific method?

Guess => Test => Data

Does Feynman say that we can prove a law?

Feynman: We cannot prove anything. We can say that something is very likely or unlikely. Questions:

- What is needed (i.e., presuppositions) for deciding that a claim such as ‘flying saucers’ do / do not exist”, or is likely / unlikely?
- What is needed to prove it? What is needed to disprove it.
- Feynman says that claims can be disproven. Is ‘disproving’ a form of proving? How can a claim be disproven (e.g. disproving that flying saucers exist)?

- Is Feynman ‘fully’ right? Compare what he says about ‘how we find a law’ with Newton’s approach.

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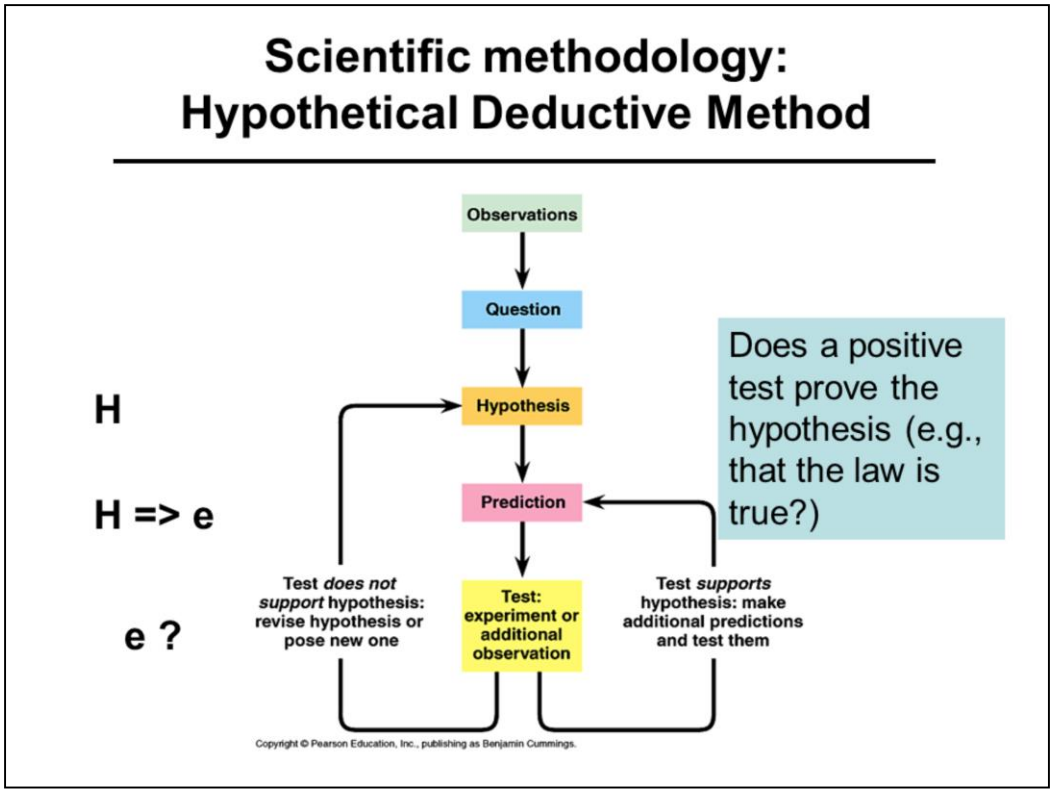
Is it possible to prove scientific knowledge?

1. Is this statement true or false: “Feynman says that we can prove a law” TRUE / FALSE
2. Does a positive outcome of a test prove the hypothesis (a positive test means that the outcome of the test agrees with the prediction)? YES / NO?
3. If NO (a positive outcome does not prove ..) Why? If YES – Why?



Later in this course this schema will be called the Hypothetical deductive method (or, the HD method in short).

Compare this schema with what Feynman told us about method. Does it agree? What does this schema say about proving or disproving? Note that if the test agrees to the prediction, we do not conclude that the hypothesis has been proven (as in that case, the arrow on the right would point back at the hypothesis and state: “proven”)! Does Feynman say that we can prove a law?

Note: This schema is not an algorithm of how scientific research actually goes about. Instead, it distinguishes between important elements, and the relations between them. The schema can help us in distinguishing between different elements in a concrete scientific research project.

In this class, the schema is applied to different examples (De Waal’s investigation of whether apes do have the ability of empathy; Kepler’s discovery of the orbit of Mars; Newton’s discovery of the laws of motion).

The way in which actual research goes about is dynamical. In a research project, we go back and forth between these elements, but still, we can point out these different elements when trying to see what is going on in a

research-project:

Clarifying remarks:

1) Observations also includes measured data. During a research project, we may come across new observations (for intance, in our experiments), that are relevant, and make us phrase the question differently.
2) Observations (both at the top op this schema, and observations done in the test) are not as straightforward as it seems. An example is the movement of bodies. When we see a change of direction or a change of speed, we ‘observe’ that a force is exerted on the body, which causes this change. Before Newtion, people did not ‘observe’ this.
3) Stating a relevant research question, is one of the most difficult and also most important parts of research. For instance, the question whether apes have emphathy is broken down to the question whether apes have a sense of fairness.
4) Based on new observations, we may change our question.
5) The hypothesis can be very simple: Yes or No (e.g., yes, animals do have a sense of fairness), or the hypothesis is an answer to a why question. In the latter case, the hypothesis is an explanation of what has been observed.
6) When using experiments for testing the hypothesis, the prediction involves the experimental set-up and the prediciton of what will happen and would support the hypothesis. For instance, the prediction is: an ape who does not have a sense of fairness, will in an experimental set-up where it gets a lesser reward for performing the same task as his mate, respond indifferently (that is, he will not behave different from when receiving the same reward). If he has a sense of fairness, he will respond upset when seeing that he gets a lesser reward.
7) A lot of debate is on whether the experimental set-up is actually a good way of testing the hypothesis. For instance, the system is too much idealized (e.g., domesticated apes rather than apes from the wild); it is a laboratory situation, which does not say much about the real-world system, etc.
8) In the test, the experimental set-up produces results that can be interpreted differently. Or, makes a stronger (more general) claim than justified.
9) The test basically is the observations made in the experiments. They either agree or disagree with what has been predicted.

Deductive Arguments (validity)

"If Hypothesis, H, then event, e, will occur".

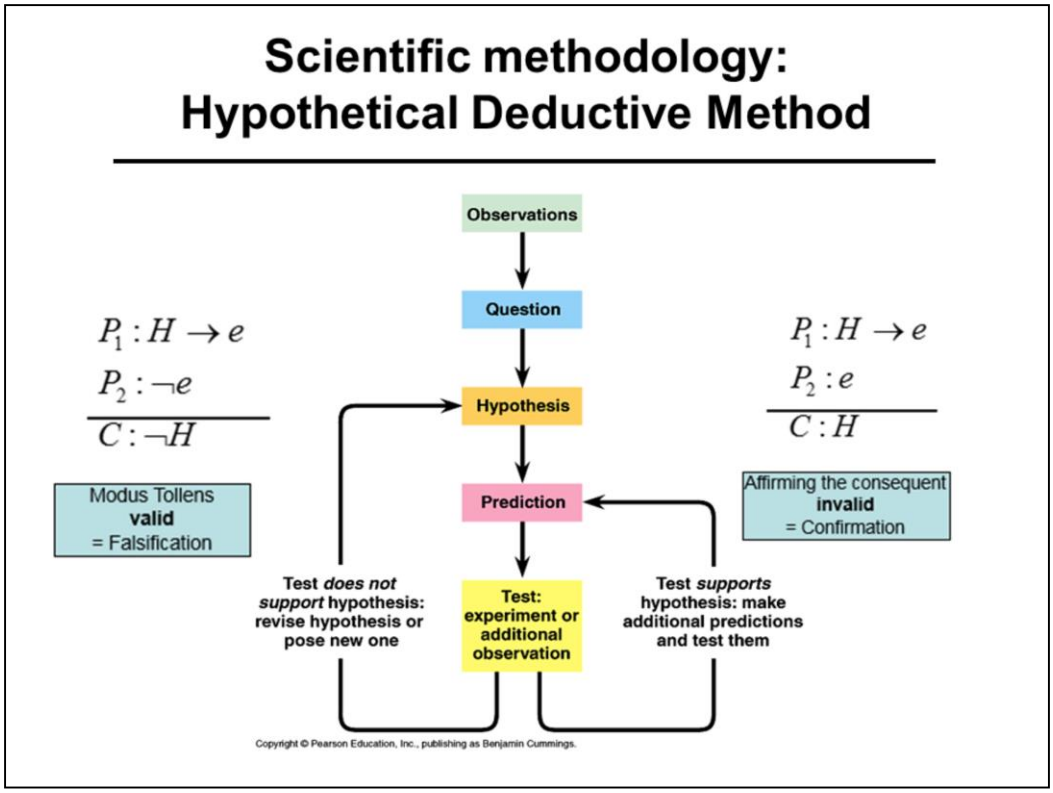
Problem of science shown by logical analysis of deductive arguments: the occurrence of the predicted event, e, does not prove that H is true!

$P_1 : H \rightarrow e$	$P_1 : H \rightarrow e$	$P_1 : H \rightarrow e$
$P_2 : H$	$P_2 : \neg e$	$P_2 : e$
$C : e$	$C : \neg H$	$C : H$
Modus Ponens **valid** = Deduction	Modus Tollens **valid** = Falsification	Affirming the consequent **invalid** = Confirmation

Assume that H is a hypothesis, and e an event predicted by this hypothesis (derived from the hypothesis by deductive reasoning). Proposition 1 (P1) says: "If it rains (H) then the streets gets wet (event e)." Because we understand the meaning of raining, we know that P1 is a true proposition. However, we do not know whether it rains at this moment. Assume that we see that it rains (hence, the sentence P2 "it rains" in schema Modus Ponens is true). Then, from combining P2 with P1, we can conclude that event e occurs (hence, in this schema, the sentence C: "the streets get wet" is true). Now suppose that we do not see that it rains, but only that the streets get wet (hence, in schema 'affirming the consequent' the sentence P2 "the streets get wet" is true). But, from combining P2 with P1, it would be logically invalid to conclude that the sentence C: "it rains" is true). [Note that this is not to say that the negation of this sentence is true! It may rain (H), but also other reasons may be given for why the streets get wet.]

Figure out which of these deductive schema's apply to testing a hypothesis in the schema on scientific methodology.

=> Logical analysis alone explains why we cannot prove a hypothesis: we cannot determine whether H is true (in Modus Ponens); we can only find out whether event e occurs in our test (in 'Affirming the consequent').



Analyse the test by means of formal logic, and explain why we cannot prove a hypothesis.

Why is it called Hypothetical-deductive? Which part is deductive reasoning? Which part involves deductive reasoning?

Is it possible to prove claims by means of scientific research?

Scientific methodology: **Epistemology** addresses the *justification* of methodologies.

A. The role of **the logical form** of scientific reasoning in scientific methodology, e.g.:

1. Deductive reasoning
2. Inductive reasoning
3. Causal reasoning (+ Manipulationism)
4. Hypothetical-deductive reasoning

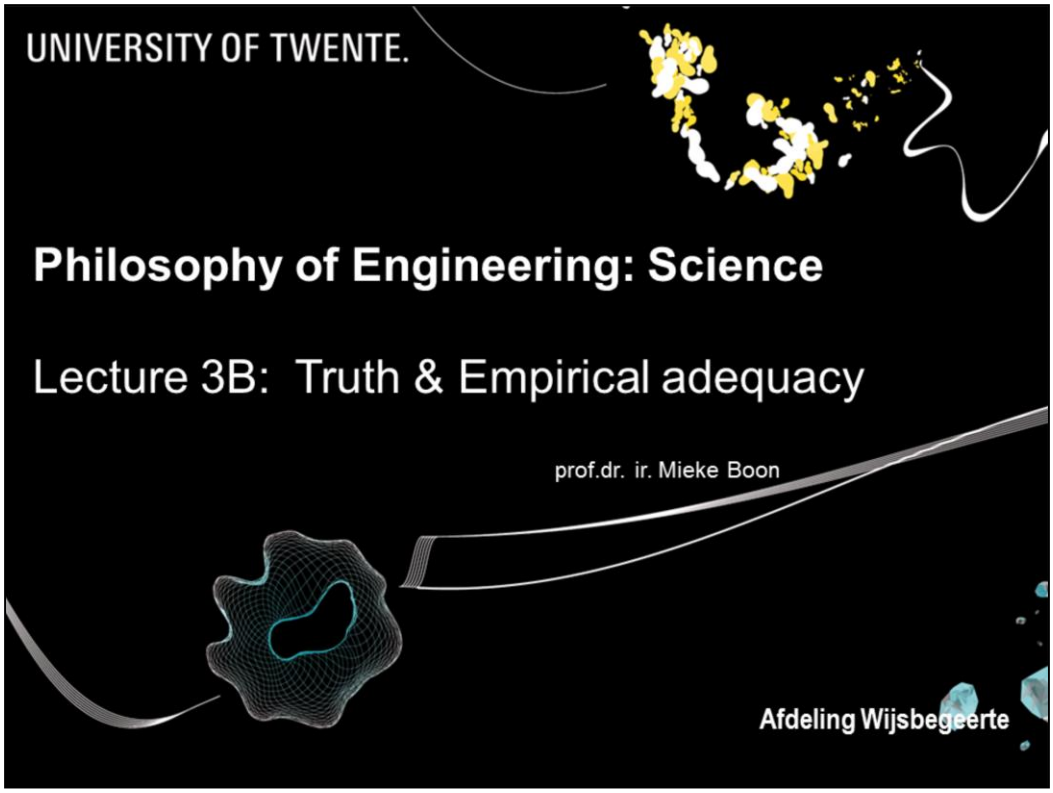
B. The role of **truth** in scientific methodology

Science talks about the (physical) world; it asks questions about the world: why, what, how questions.

Philosophy of sciences talks about science; it asks questions about science: why, what, how questions.

Relevance Philosophy of Science?

1. Can we trust science and scientific knowledge?
2. Why do we trust scientific results? When do we distrust it? (Why) should we accept the results?
3. PhoSc: How do scientists produce scientific knowledge? How do they prove (or validate) scientific knowledge? And methodology?
4. How do they use it (e.g. in technology and in forcasting) and how can this use be validated?


UNIVERSITY OF TWENTE.
Philosophy of Engineering: Science
Lecture 3B: Truth & Empirical adequacy
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Afdeling Wijsbegeerte

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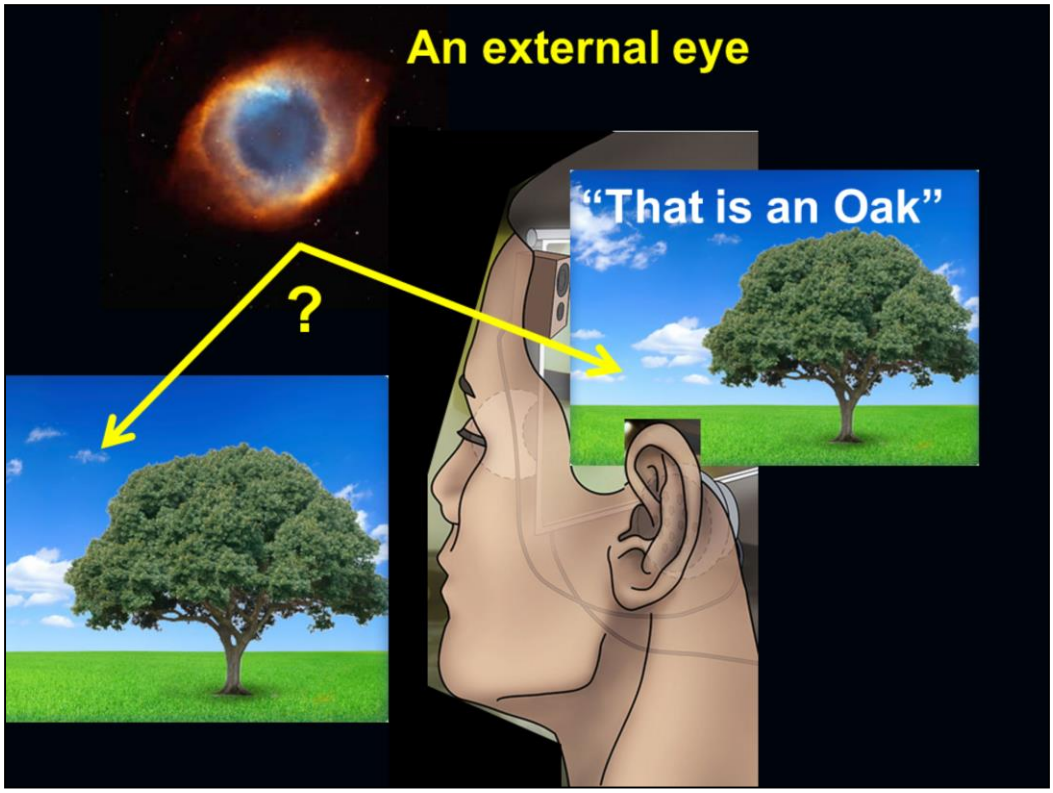
What does 'truth' mean?

1. What does 'true' mean: what does the term 'true' refer to, and try to give a definition of truth.
2. What does '**empirical adequacy**' mean: what does the term *refer to*, and try to give a *definition*

Correspondence notion of truth

Knowledge *corresponds* to World.

David Hume again: True knowledge means that the idea in the mind corresponds to the world outside the mind.

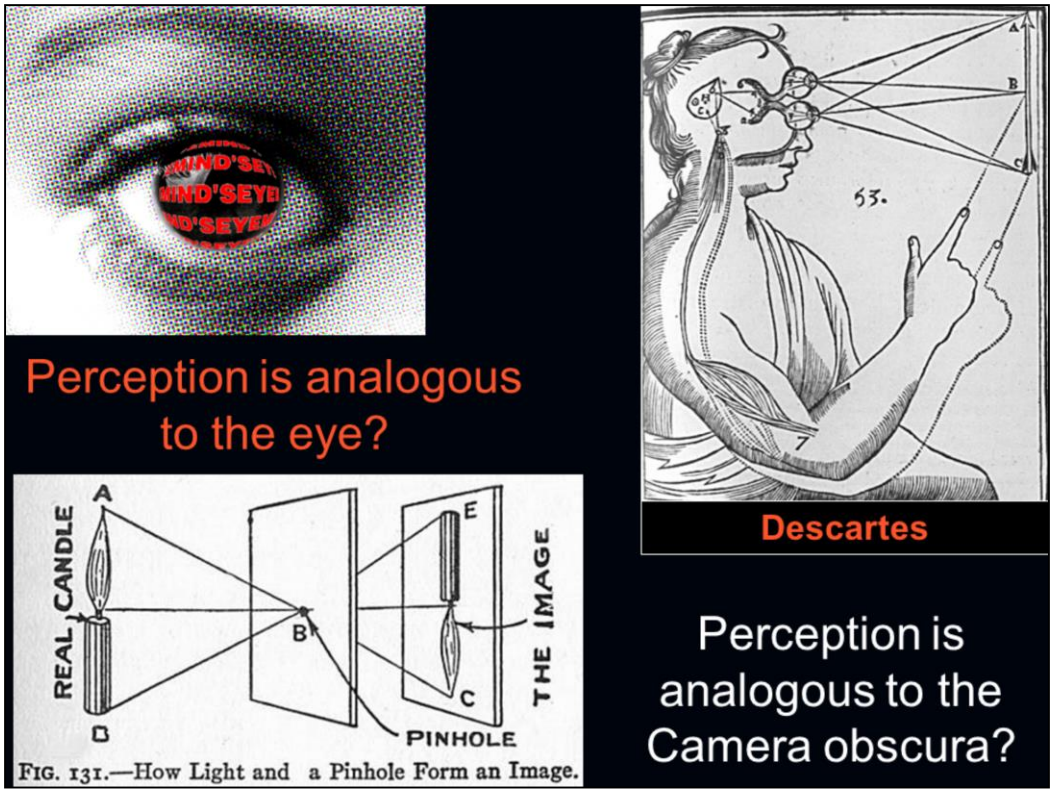


David Hume and other philosophers at that time believed that observations are a kind of imprints in our minds, through which knowledge is produced. He called knowledge through such observations ‘ideas’. These ideas are in the mind. [Recall that Hume was an Empiricist regarding the solid ground of knowledge: all knowledge much be obtained by means of observation / perception. More complex knowledge can be traced back to simple ideas.] Hume’s conception of how we attain simple ideas is (very much simplified) depicted here.

In brief, true knowledge means that the idea in the mind corresponds to the world outside the mind.

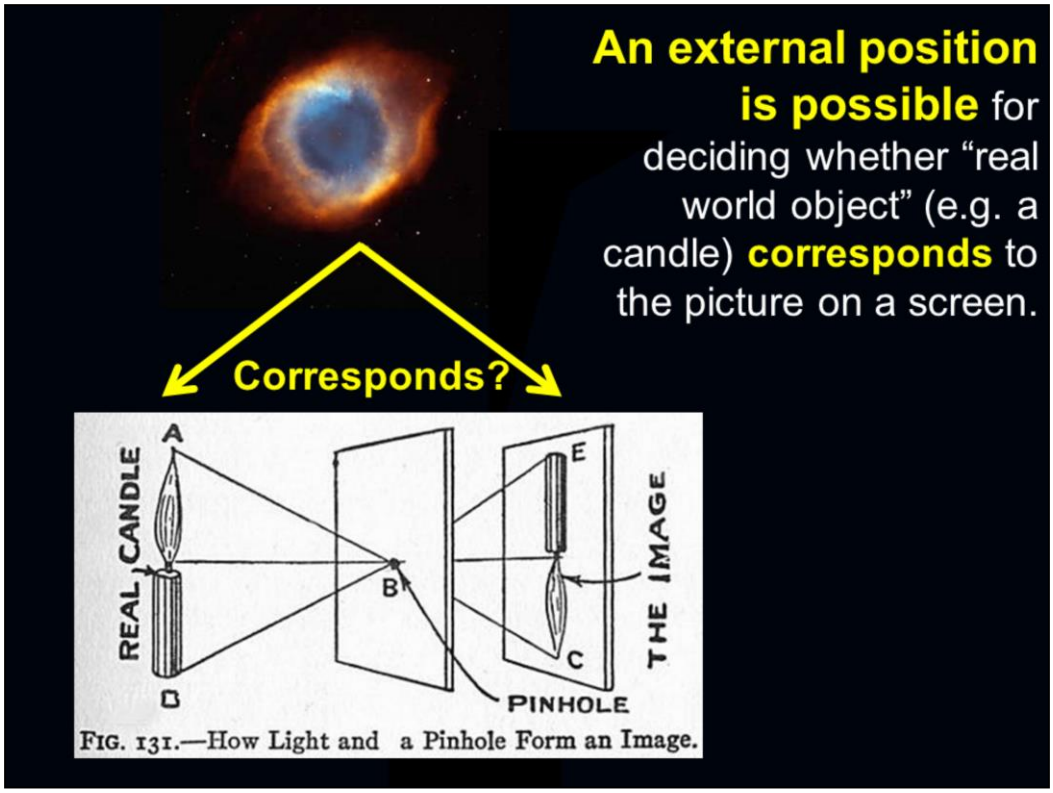
But now a clever philosopher asks how we can know (‘justify’) that the idea in the mind corresponds to the world? [see yellow arrows]

This remained an unsolved puzzle. Some philosophers have argued that we can trust that this is the case because God will not deceive us (Descartes). Other philosophers have made the problem even clearer by arguing that comparison of the world out there and the picture in our mind would require an external eye (a ‘God’s eye view’). And, for humans, this position is impossible in principle!



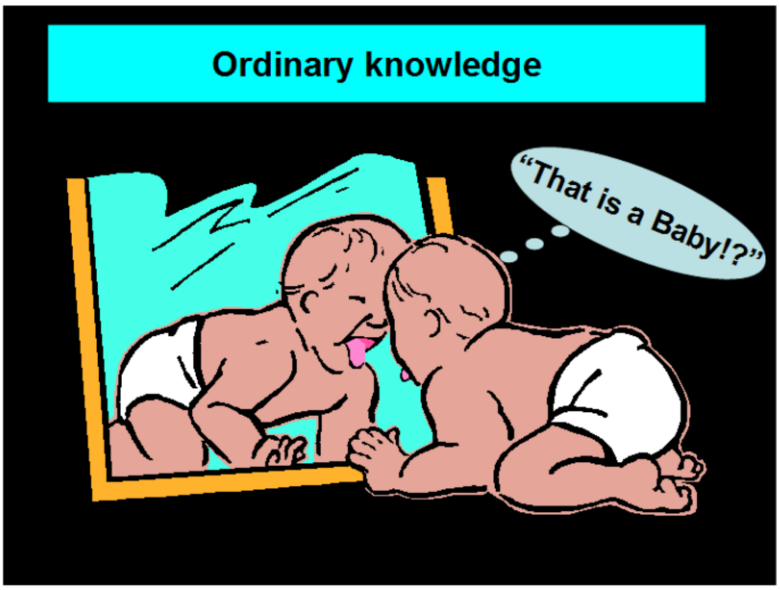
Naive picture of objectivity in observation: Image is projected in the eye (or mind) similar to how an image of a real object is projected in the Camera Obscura.

In trying to understand how knowledge comes about, the understanding of the working of the Camera Obscura and the workings of the eye have been important metaphors.



The Camera Obscura as a metaphor for ordinary knowledge. "An external eye" that compares world and knowledge (pictures or sentences about the world) is possible. => A common sensical position. Concerning 'ordinary knowledge', the external position is (or, at least, seems to be) possible for us. So, we can compare the real, material candle (which is observable in a more or less unproblematic manner) with the image at the back of the Camera Obscura (this picture is also observable in a more or less unproblematic manner), and decide that the image *corresponds* to the real picture.

What does it mean to say that a sentence is true?



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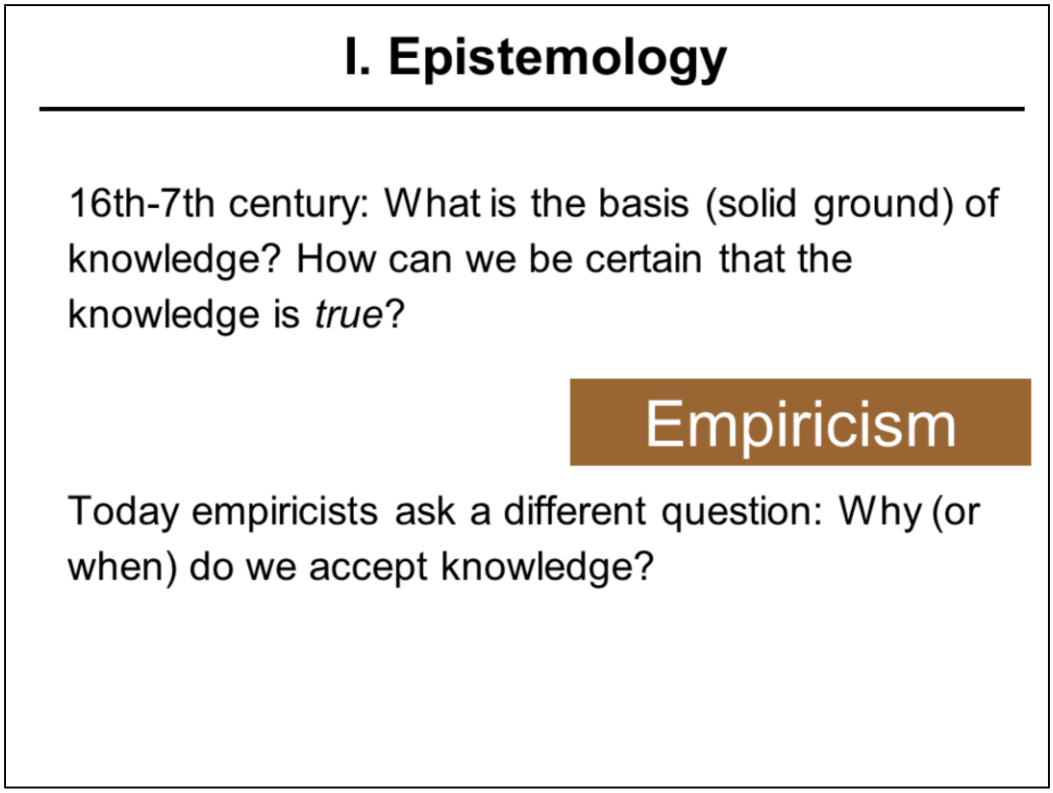

Modern philosophers stepped away from the problematic assumption of (empirical) knowledge as some kind of correspondence between an idea (or picture) in the mind and the external world. Instead, they argued that truth concerns the relationship between language (sentence) and the external world [rather than the relationship between the image in our (individual) minds and the external world].

Hence, although many philosophers still agree to Empiricism (such as articulated by David Hume), they disagree with Hume's account of how observation leads to true knowledge – that is, they disagree that knowledge results from some kind of imprint in the mind [where the imprint somehow corresponds to the external world.]

Why (or when) do we accept knowledge?

"We accept (or trust) knowledge (e.g., a sentence "p") ***because*** it is true."

Hence: Truth is an epistemological criterion for accepting sentence "p".

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This slide summarizes the message of this class.

Notes are limited, as explanation is given in separate text document "Truth and empirical adequacy".

We will not start with the typical philosophical question "what is truth?"

Let us start from the question *why* 'truth' is important with regard to (scientific) knowledge. Why is the notion of true/false important – why does 'truth' matter?

[Recall that true/false applies to the content of propositions, whereas valid/invald applies to the 'empty' logical structure of an argument.]

Assume that you point at the table and say: "This table is white." You and I may agree that this table is (or is not) white. If the table is white, we can state that the sentence "This table is white" is true.

[Some people may have a philosophical inclination (which I will not encourage), thus asking whether this table is 'really' white. They say, "you and I may agree that this table is white, but is it *really* white, independent of what we believe?" What does it mean to ask such a question? Either it indicates

that this person attaches to Hume's problem ("how do I know that the knowledge in my mind corresponds to the real object"), or, this person believes that there is an independent world, which determines whether or not this table is white, independent of what we believe. This kind of belief is closely related to what is often called Platonism (there exist independent Ideas of 'White', 'Good', 'Large,' 'One', 'Horse', 'Man', 'Metal'), or realism (versus nominalism). In this course, I propose to leave these discussions to philosophers.]

Does truth matter? Some people say 'Truth does not exist', or 'there is no Truth'. When saying this, they may have in mind a correspondence or a Platonistic notion of truth. So, in a philosophical mood, you may claim that you do not believe in Truth. Or, in a relativistic, cynical or skepitcal mood, someone may claim that everyone has his or her own truth, and so, truth does not really matter anymore.

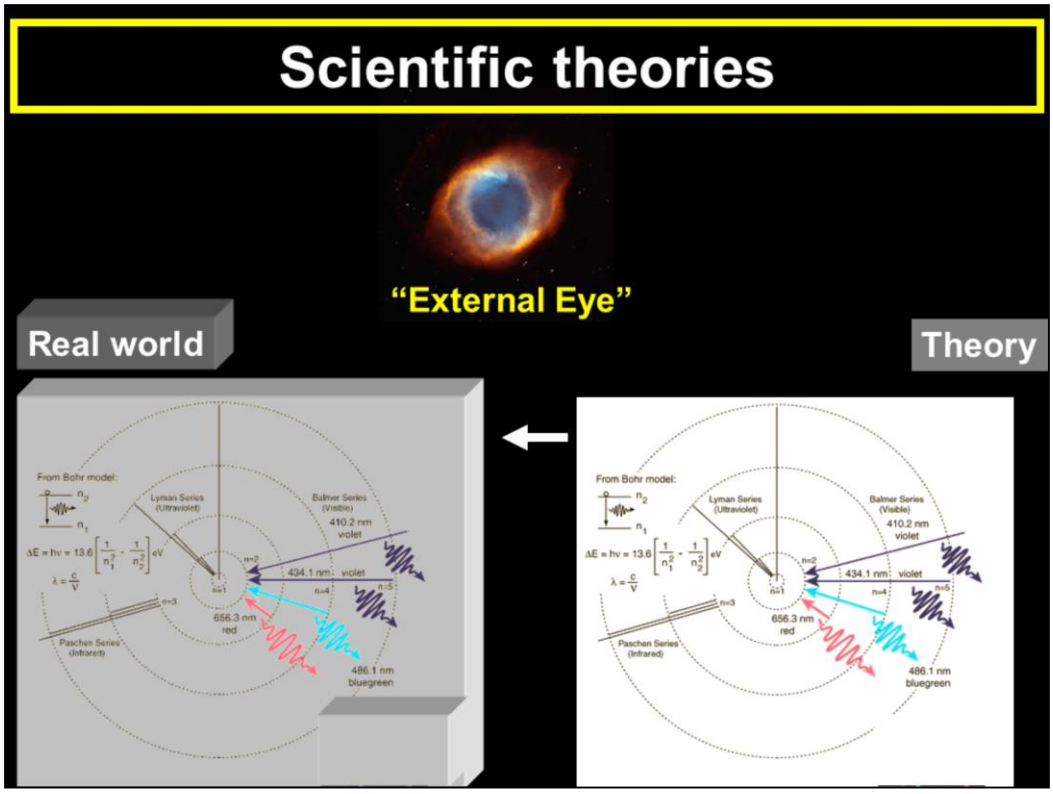
However, in ordinary language, truth still matters:

Assume that you say to the policeman: "You are wrong in claiming that I drove through a red light(at x,y,z,t)." This sentence can be restated as: "It is not true that I drove through a red light (at x,y,z,t)." In other words, the sentence "I drove through a red light (at x,y,z,t)" is false. Certainly, it matters whether this sentence is true or false.

So, let us start from the idea that truth somehow plays a role in the **acceptance or rejection of a claim**. In other words: we accept a knowledge claim (for instance, the sentence "I drove through a red light (at x,y,z,t).") *because* this sentence is true.

At this point, the problem how we know that this criterion ('truth') applies to a sentence still needs to be answered. Traditionally, we assume that a sentence is true if it *corresponds* to how the world is (or how the world 'really' is, as a Platonist may say).

In this class, it will be explained that on this use, 'truth' must be understood as an *epistemological criterion*. It is a criterion for accepting a sentence (or a claim) "p". Recall that 'Episteme' means knowledge, so 'epistemological criterion' means a criterion for accepting a claim "p" as knowledge. We will now explore whether other epistemological criteria are possible as well for the acceptance of knowledge: does it necessarily involve 'truth', or are other candidates possible? That is, are other epistemological criteria for the acceptance of knowledge possible.



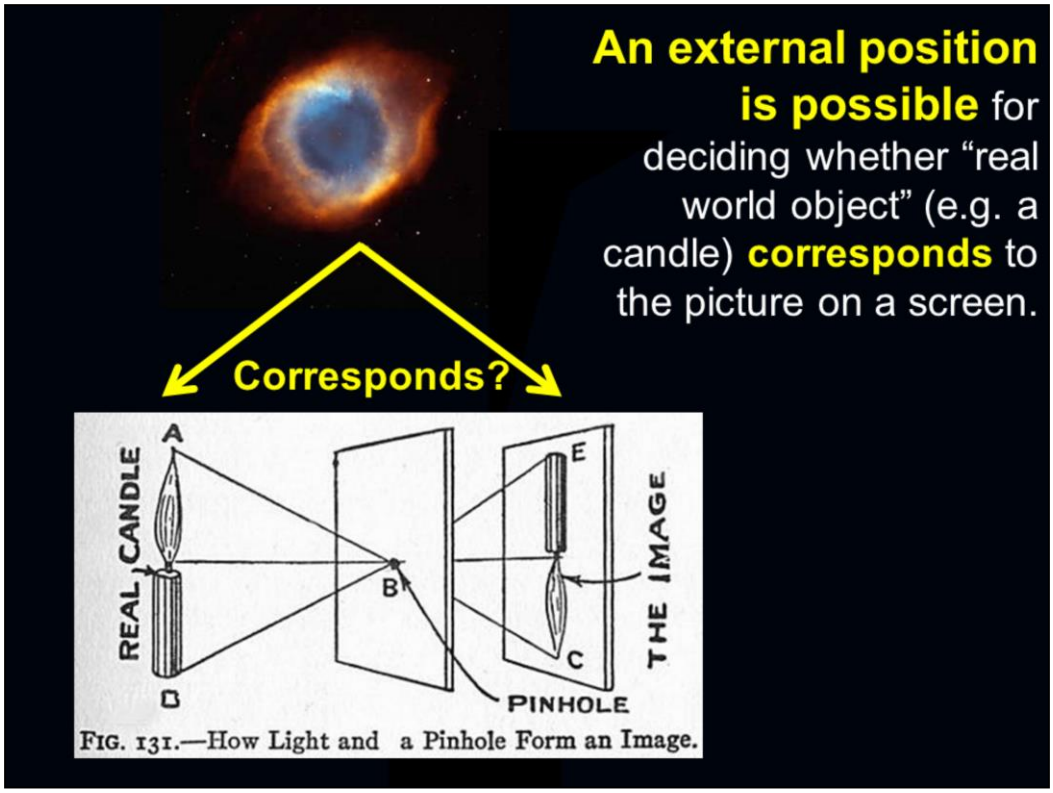
If we use this metaphor to analyze what many people have in mind when it comes to scientific knowledge, the scientific model (or theory) would be a representation (a picture or description) of a real object and/or process.

One problem is that it is impossible for scientists to compare in an unproblematic manner the supposed real, material object or process with the scientific model [that is, they cannot compare it in a manner similar to how humans compare the real, material candle with the image at the back of the Camera Obscura.]

Clearly, this is not to say that the world is not corresponding to what the theory tells! The only thing is that we cannot <u>know</u> whether this is the case.

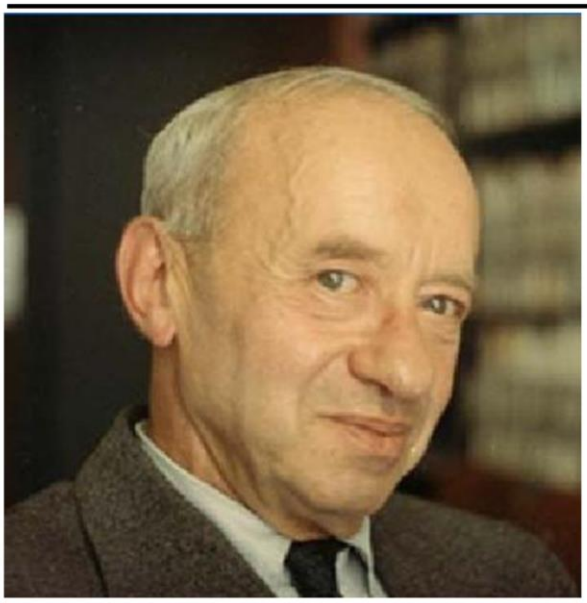
S*cientific realists* use the so-called 'Miracle argument' to argue that there must at least some truth in theories: They admit that the truth of scientific theories cannot be proven. However, scientific theories are the best explanation for the occurrence of the phenomena, and the successes of at least some theories would be unintelligible, unless we assume that they are approximately true!

Constructivists argue that there may be other possible explanations for the 'empirical adequacy' and 'explanatory power' of these theories.


An external position is possible for deciding whether "real world object" (e.g. a candle) corresponds to the picture on a screen.
Corresponds?
REAL CANDLE
A
B
B'
E
C
PINHOLE
THE IMAGE
FIG. 131.—How Light and a Pinhole Form an Image.

Tarski's Semantic conception of 'truth'

http://www.jfsowa.com/logic/tarski.htm#1 (1944)



Alfred Tarski (1901-1983)

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Alfred Tarski was a logician. He is one of the first philosophers who spelled out a revised notion of truth in empiricism, which no longer draws on correspondence between ideas in the mind and the external world, but instead, on a relationship between the content of sentences and the external world.

Accordingly, Tarski proposed the so-called 'semantic conception of truth.'

Tarski's Semantic conception of 'truth'

http://www.jfsowa.com/logic/tarski.htm#1 (1944)

Semantics is a discipline which, speaking loosely, *deals with the relation between expressions of a language and the objects* (or "states of affairs") *"referred to" by those expressions.*

Semantic notions (are properties that) apply to *expressions of a language rather than to the objects* ….

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In order to get the message across, the next few slides are extremely brief and schematic and seemingly simple. However, beware: the majority of the students clearly miss the point and give a wrong answer to this question on the exam. In order to test yourself, it is strongly recommended to write down the argument given here, without using the lecture notes.

Hence, 'expressions of a language' versus 'ideas or pictures in the mind'.

Semantic notions are properties that apply to expressions of a language . Note that 'true' is considered as a property of something else. The logical structure of using 'true' as a property of a sentence is similar to how a property (such as 'green') applies to objects (such as 'apple').

[Formaly, we should use 'predicate' rather than 'property', as a predicate is a linguistic (rather than a physical) entity. Every complete sentence has a subject and a predicate, such as "the apple (subject) is green (predicate)"]

Tarski's Semantic Conception of 'truth'

http://www.jfsowa.com/logic/tarski.htm#1 (1944)

Real World	Language	Meta-Language
Physical objects, properties, relationships (e.g. causal relationships): **Observable versus Unobservable objects etc.**	*About* the world. "refers to" "represents"objects, properties, relations in real world: **Sentences, laws, theories, models,…**	*About* language and concepts. Domain of philosophy / logic (e.g. analysis of semantic concepts such as 'truth').

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Tarski's Semantic definition of 'truth'

http://www.jfsowa.com/logic/tarski.htm#1 (1944)

Step 1: True and false apply to sentences (propositions) => Truth is a *semantic* notion: truth is about the *relation* between sentences and the world.

Step 2: Tarski's definition of 'truth':

"p" is true *iff* p.

In words: the sentence named "p" is true if and only if what this sentence says is the case (i.e. "p" is true *iff* p is the case).

The symbol (or name) for a sentence is "p" (like, when we write: Jane said about her cat, "the cat is old").

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Tarski's Semantic definition of 'truth'

Why do we need a definition of truth?

Truth is a property of a sentence (not of objects).

How do we learn the meaning of this property? Compare: "The apple is red" versus "The sentence is true".

Learning by designation versus definition.

Learning the meaning of 'truth' requires a definition of this notion.

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The question is now: How do we learn the meaning of this property?

In many cases we learn the meaning of a concept (of, say, 'apple' or 'green') by designation. But we cannot learn the meaning of truth by designation. This is why we need a definition.

Why (or when) do we accept knowledge?

"We accept knowledge (e.g., a sentence "p") ***because*** it is true."

But: How do we know whether "p" is true?
How do we know (or justify) that what p says is actually the case?

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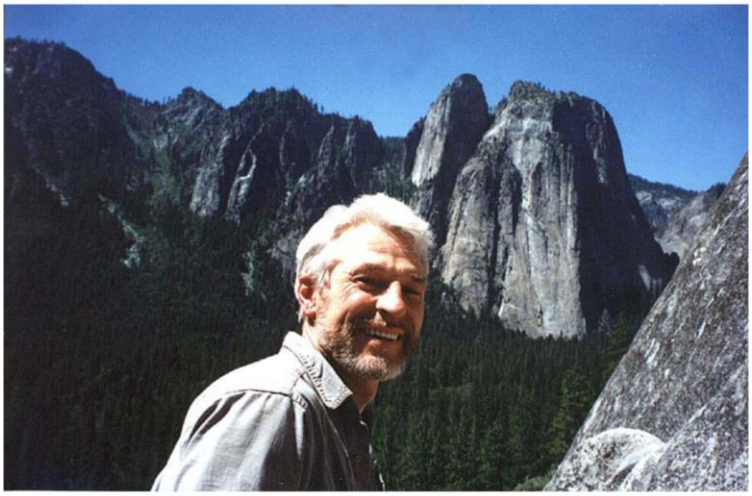
We know whether a sentence "p" is true in case this sentence describes an observable state of affairs p. But it becomes problematic when "p" describes an unobserable state of affairs.

Bas Van Fraassen's Semantic Conception of 'empirical adequacy' as alternative to 'truth'



Bas Van Fraassen (1941-)

Empiricism

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Bas Van Fraassen is a contemporary empiricist. He is also a so-called an 'anti-realist', or a 'constructive empiricist' as he prefers to call his own position. The core of his position is very similar to Hume's empiricism, namely, that we cannot have knowledge of 'the world behind the observable phenomena' in the same way of having knowledge of observable (perceivable) phenomena (e.g., "the tree weighs 1349 kilograms").

Note that he does not deny that there exists a world behind the phenomena. His question is, what kind of knowledge we have of it – can we have certain, true knowledge of the world 'behind the phenomena'. Hume said 'No'. But this position is unsatisfactory given the successes of modern science. Van Fraassen aims at a more refined position. He argues that the predicate 'true' should be exclusively reserved for knowledge of the observable (perceivable) world, whereas this notion is 'meaningless' regarding theoretical knowledge.

How do we know whether "p" is true? How do we know (or justify) that *what* p says is actually the case?

Empiricists assume that 'in the end' all our knowledge of the world must be justified in observations (more precise: by 'sense-experience').

(Modern) empiricists like Bas Van Fraassen (1980):

- We can only decide whether "p" is true (that is, whether what p says is the case), if we can observe that p.
- Therefore: Observation (perception) is a methodological criterion for deciding whether what p says is the case.

Empiricism

Recall that a sentence "p" is a knowledge claim. Knowledge is a (true or correct) description of something.

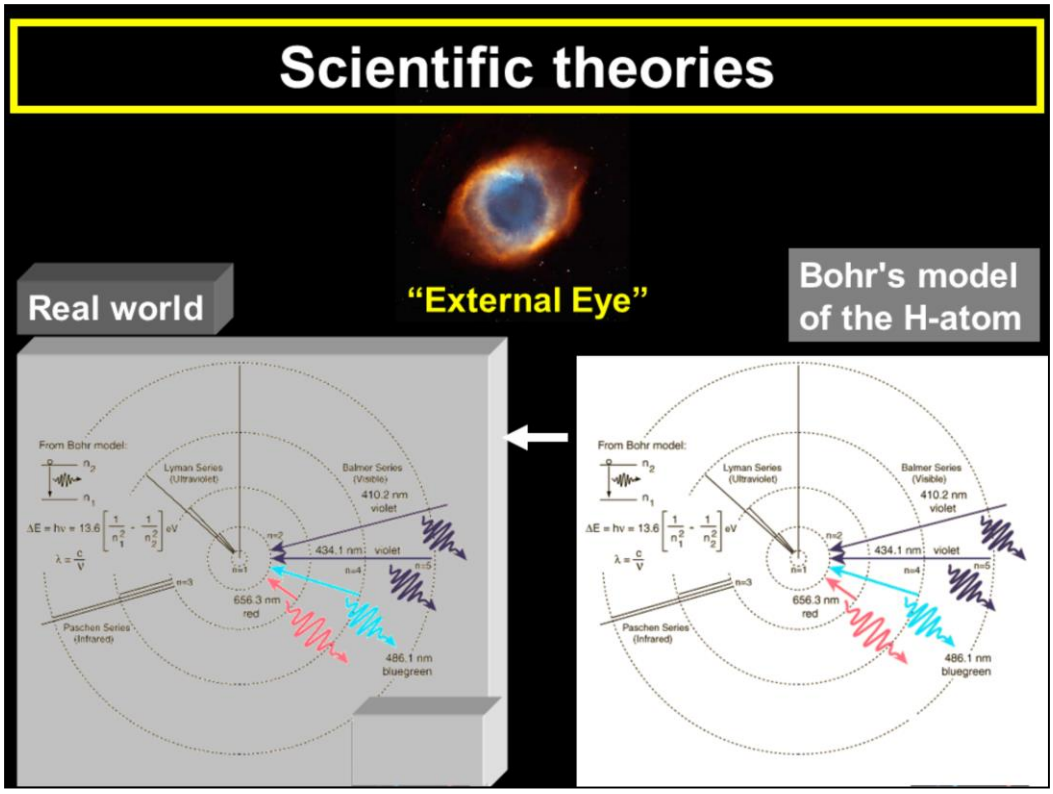
How do we know that what theory T says is actually the case?

Methodological criterion for deciding whether what a sentence p, but also theory T!, says is the case.

Applying this criterion: What theory T says is actually the case *iff* 'what theory T says is actually the case' is determined (or tested or checked) by a methodology that is based on direct observation.

Problem for empiricism is that this comparison between what theory T says and how world is cannot be made through observation.
(see metaphor on next slide)

Empiricism



This slide aims to explain visually, that:

Claiming that a theory is true, would mean that the theory (e.g., Bohr's model of the hydrogen atom) is a true picture or description of 'what the world behind the phenomenon is like'. In other words, the theory (= picture and/or description) **corresponds** (or, is similar) to something in the world. [Recall that the same idea was used earlier: truth means that the picture or idea in the mind corresponds with the world (or, more precise, 'a state of affairs'.] The point (of Van Fraassen) is that we cannot know whether this correspondence is the case. We do not have a methodology to find out whether the model corresponds to something in the world. [Recall the metaphor of the Camera Obscura: in that situation, the image of the candle on the wall can be compared with the real candle.]

Metaphorically speaking, a very special kind of external eye would be needed to compare the theory and the world. This position is not possible for human beings.

Maxwell's laws are true?

- What does it mean when we claim that Maxwell's laws are true?
- According to Tarki's definition: "p" is true iff p. In words: sentence "p" is true if and only if what this sentence says is the case (i.e. iff p is the case).
- Therefore: Maxwell's laws (which are 'sentences') are true, if what these laws say is (literally) the case.
- But what do we mean by claiming that, what these laws say is the case? Tarski's definition does not mean to say: what these laws predict is the case!!

How do we know whether "T" is true? A criterion for truth according to Empiricists.

The truth criterion of empiricists for "T" is that T is observed, and involves that what "T" says somehow 'corresponds' with a state of affairs T.

Van Fraassen's defence of anti-realism: 'Truth of a theory "T"' would require that: *theories* can *give us a literally true story of what the world is like*

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Empirical adequacy

Van Fraassen (1980) rejects so-called realism, that is, the idea that theories are literal stories or pictures of how 'the world behind the phenomena' is.

His **anti-realism** entails that truth does not apply to theoretical knowledge. He proposes *empirical adequacy* of theories as an alternative to their truth.

His definition of empirical adequacy: A theory or law is empirically adequate if what it says about observable things and events in the world is true.

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The point is now that we have two different properties of sentences: 'true' and 'empirically adequate'.

[Rough and dirty:] According to Van Fraassen, only when a sentence, "p", describes an observable (perceivable) state of affairs, p, the property 'true' or 'false' can be attributed to that sentence. In brief, we can claim that **"p" is true**.

If, however, a sentence, "T" intends to describe an unobservable state of affairs, T, the property 'true' cannot be attributed. For instance, when "T" is Bohr's model of the atom, or Maxwell's theory. In other words, claiming that "T" is true is wrong as the way in which the property has been attributed does not meet the methodological criterion (observation). [According to Van Fraassen].

Said differently: we cannot, by means of direct observation determine whether Bohr's model of the hydrogen atom corresponds (or, correctly *represents*) to the real hydrogen atom.

At the same time, we can, by means of direct observation determine whether predictions made by means of "T" are true. For instance, the Bohr model may predict that more spectral lines at shorter wavelength will be found at higher temperatures. If we observe such an occurrence, we say that the sentence "hydrogen gas in an emission spectrum experiment at higher temperatures produces spectral lines at shorter wavelength" is true.

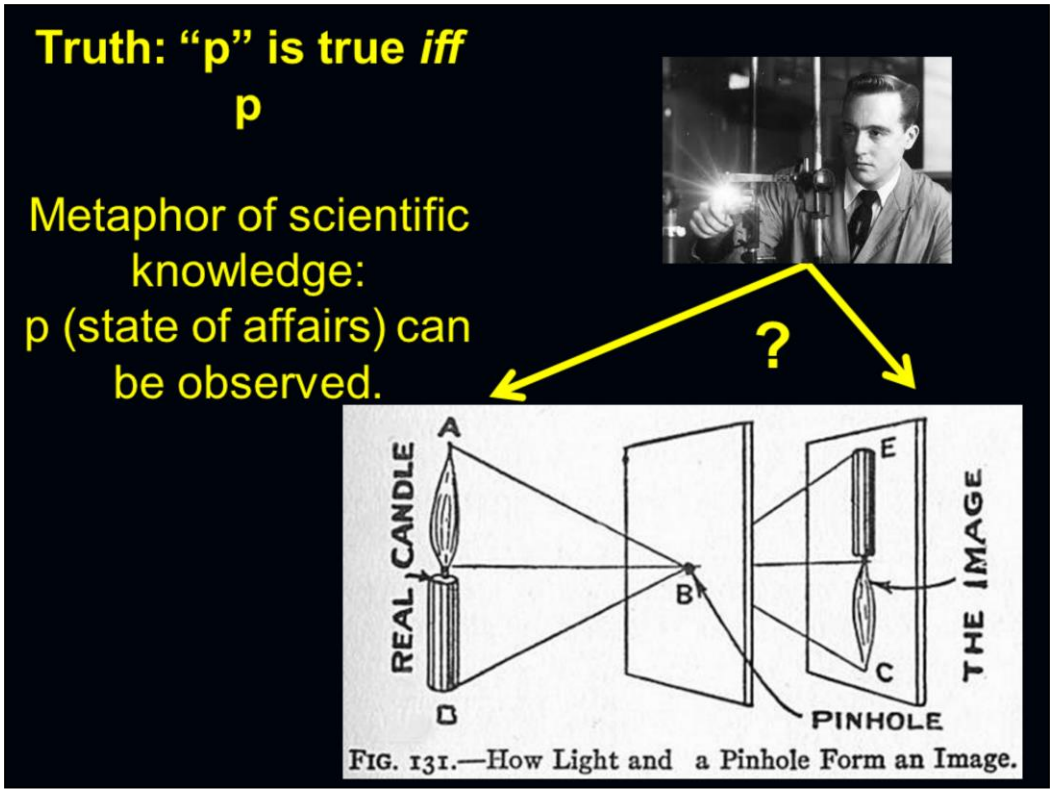
Van Fraassen's proposal is that from such finding we conclude that the theory is empirically adequate.

Summary:

For an observable state of affairs: "p" is true or false.

For an unobservable state of affairs (such as described by theory "T"): "T" is empirically (in)adequate.

Note that Van Fraassen's notion of 'empirical adequate' has a fundamentally different meaning (= definition) than the meaning (= definition) of 'true'. A common error is to say that 'empirically adequate' theories are approximately true. No, they are not.

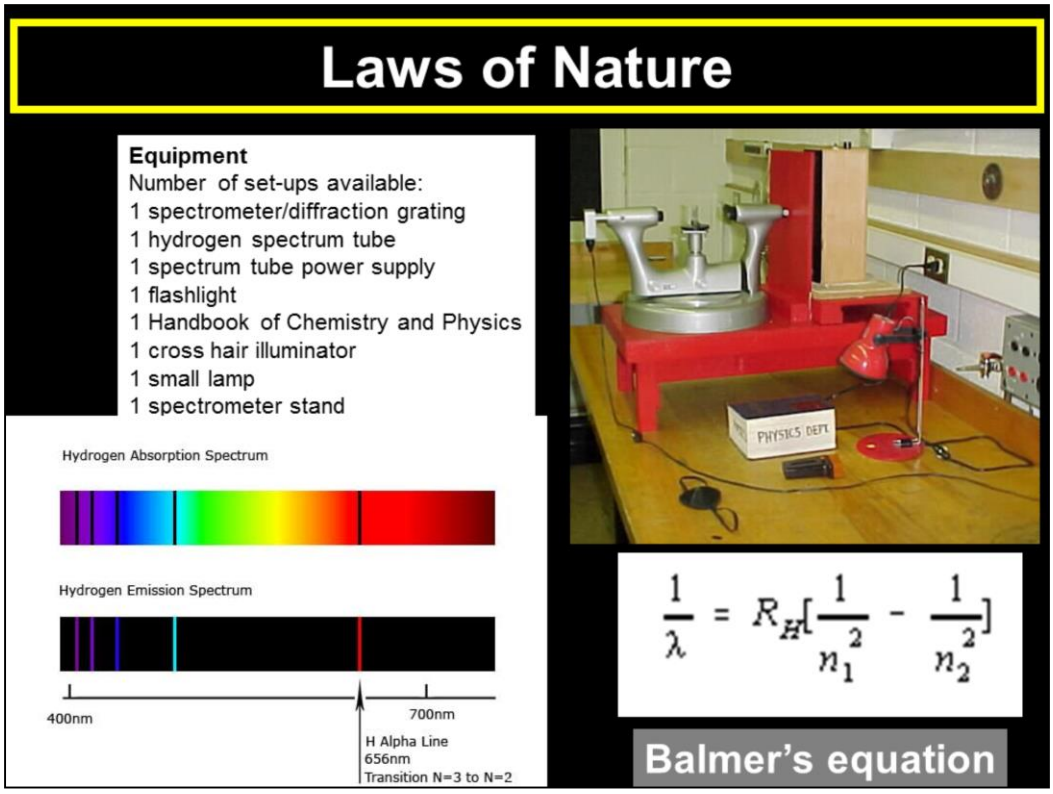


So-called 'scientific realism' adopts the 'mirror image' of knowledge.

This idea can be explained by the following metaphor: Determining whether a claim or a picture or representation is true requires that the claim or the picture or representation can be compared (by means of observation or 'direct perception) with the real object it is a representation off.

In this metaphor, the external observer position is possible: the scientist can compare in an unproblematic manner the real, material candle with the image at the back of the Camera Obscura, and decide that the image corresponds to the real object.

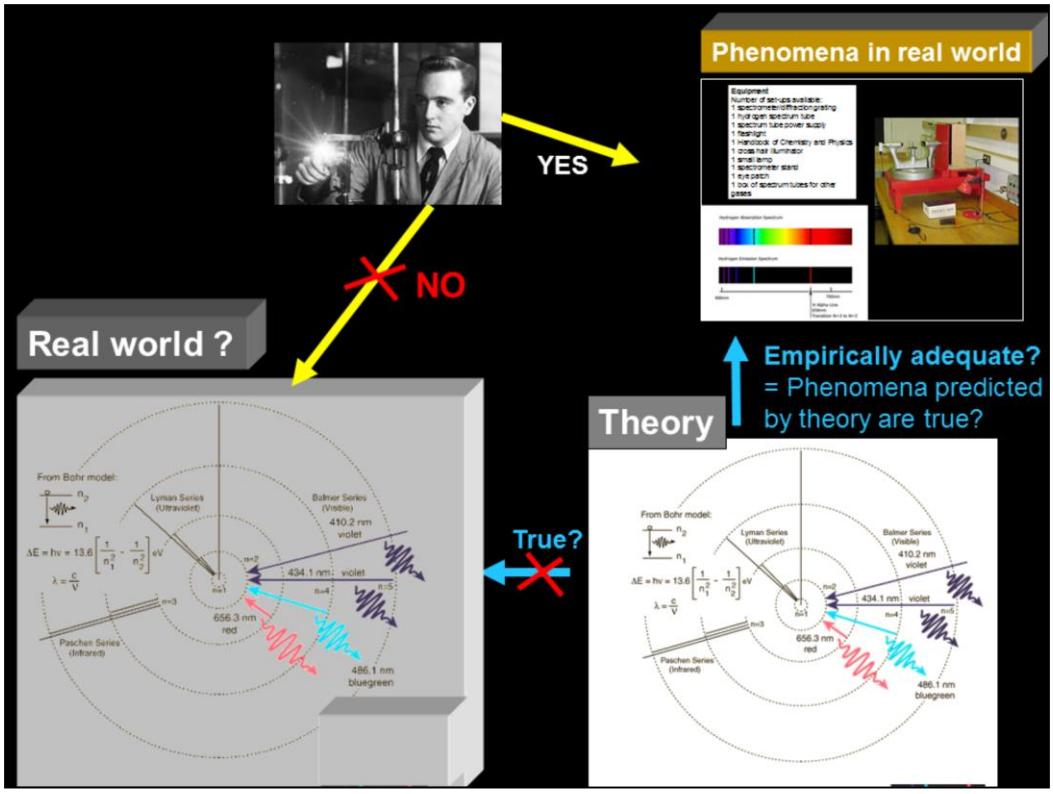
Is this metaphor ('the mirror image of knowledge') adequate for scientific knowledge?



In this experimental device, the absorption or emission spectrum of a gas, such as hydrogen gas, is measured. In this measurement several absorbtion, respectively, emission lines are measured (meaning that a very specific wavelength in of the light-spectrum is being absorbed or produced). The axis is the wave-length in nanometers, from which the wave-length of lines can be determined. The scientist, such as Balmer, aims at a mathematical description of these lines (which is an example of inductive reasoning). This equation predicts the wavelength of emission or absorption lines.

This is the Balmer equation. Similar to Hooke, who used different kinds of springs in his measurement (finding that Hooke's law applied with varying values of the elasticity coefficient), Balmer used different kinds of gasses and found that this equation applied, with varying values of R, which is gas-specific.

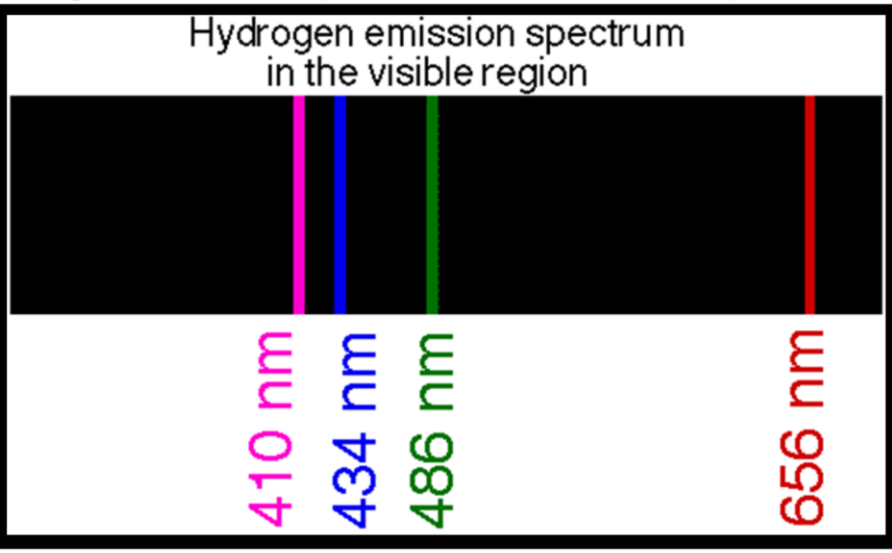
Yet, this equation is not considered as an explanation of why hydrogen absorbs or emits light at specific wave-length. Scientists will aim at a 'deeper' explanation.



This deeper explanation is Bohr's model of the atom, which tells that electron jump between levels, emitting (when jumping from high to low) or absorbing (when jumping from low to higher energy levels) photons (= light particles, which have a specific wavelength).

Empirical adequacy of Bohr's model means that the predictions made by this theory are true. So, the model correctly predicts the absorbtion and emission spectra produced in spectrometry.

Example of empirical adequacy: Observable phenomenon: hydrogen emission spectrum measured in a spectrometer



The Bohr model is <u>empirically adequate</u> because what it says (predicts) about the emission spectrum (the phenomenon that can be observed) is true.

The observable prediction.

How do we know whether theory T is empirically adequate (EA)?
Methodological criterion for EA (according to Empiricists).

A theory or law "T" is empirically adequate if what it says about observable things and events in the world is true.

For instance: "Maxwell's laws are empirically adequate" means that the measurable data we predict by means of these laws (i.e. 'what these laws say about observable things and events') are (partially) isomorphic to the actually measured data. The measured data are observed, and agreement (isomorphism) between prediction and observation (the measured data), in turn, can be observed by means of comparing them (e.g., in a graph).

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In case of observations by means of measurement, we test (by means of observation) whether our measurement outcome agree with the outcomes predicted by the theory ""T". Hence, we observe (and decide) whether the measurements are isomorphic with the prediction. Assume that the prediction "p" is "the measurement outcome is 2", and we find that the measurement apparatus shows 2, than we will conclude that "p" is true, and that the theory, "T" is empirically adequate.

One of the advantages of the notion "empirically adequacy" is that it allows for saying that Newtonian mechanics is empirically adequate for 'Newtonian systems', whereas it is inadequate for relativistic systems.

Semantic notions: *Empirical adequacy* versus *truth*

Instead of claiming that Bohr's model or Maxwell's laws are *true*, we have a new semantic notion which enables us to make a different claim:

- Bohr's model is *empirically adequate*
- Maxwell EM theory is *empirically adequate*.

Truth and empirical adequacy are about the meaning of scientific knowledge,

i.e., an answer to why we accept it as (scientific) knowledge: *because* it is true, or *because* it is empirically adequate.

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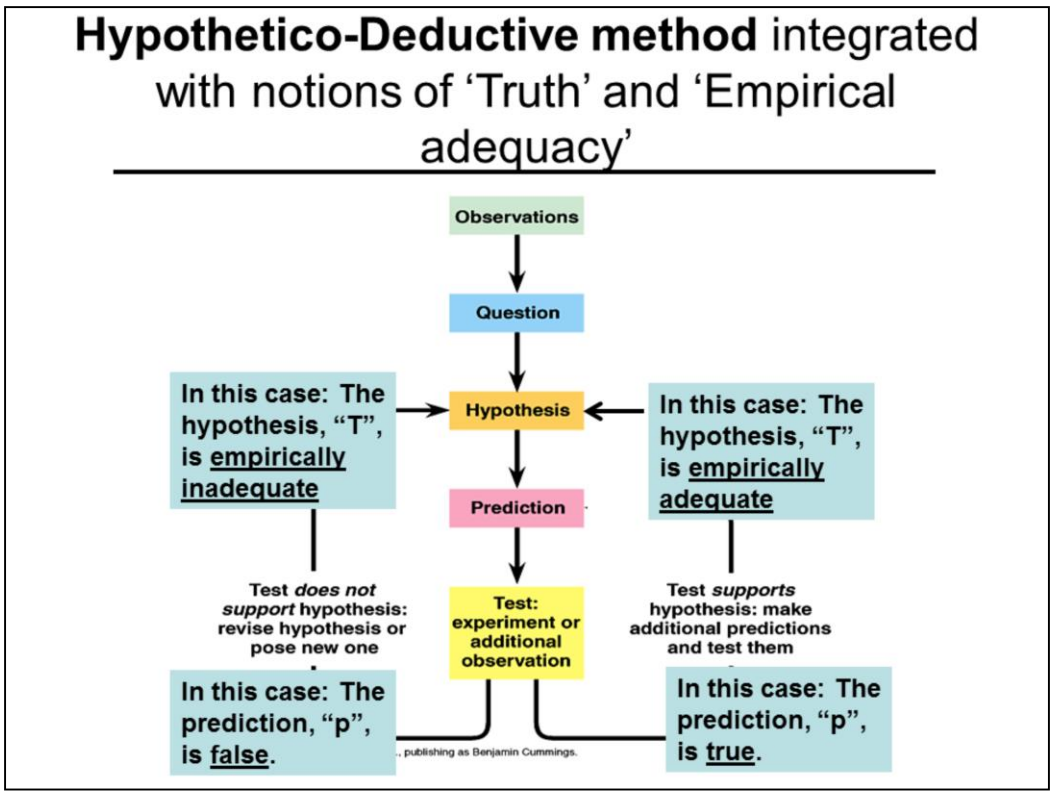
Why is making this distinction relevant to you?

1. Societal relevance: defending science against too far-fletching skepticism about science (e.g. "science cannot prove any knowledge, so why should we believe science?"
2. Forces us to be cautious about scientific results: they are empirically adequate, but this claim is less strong than claiming truth.



The notion 'empirical adequacy' merged with the HD-method. The prediction "p" is true or false (if the measurement, p, agrees with the "p", which is deduced from the theory). The Hypothesis "H" (e.g., Bohr's model of the atom) is then empirically (in-)adequate.

Summarizing the outcome of this lecture:

The notion 'empirical adequacy' merged with the HD-method. The prediction "p" is true or false (if the measurement, p, agrees with the "p", which is deduced from the theory). The Hypothesis "H" (e.g., Bohr's model of the atom) is then empirically (in-)adequate.

The topic in the next class will be to explore how the hypothesis in this diagram comes about. How do scientists construct a hypothesis? Especially, if the hypothesis is not attained by means of mere inductive reasoning (e.g. from observing that A1 is B, and A2 is B,…, Ai is B, to the hypothesis that All A's are B's), but if the hypothesis aims to **explain**, for instance, "Why 'All A's are B'".

IBE Inference to the best explanation / Abductive Arguments (invalid)

"The Hypothesis, H, is the best explanation (given facts we know, and given background knowledge that we have) for the occurrence of event, e."

H = "it has been raining" is the best explanation for the event *e* that "the streets are wet." Feynman: H = "flying sourcers exist" is not the best explanation for observed events e.

However, here also, logical structure for proving H is invalid.

$$\frac{P_1 : H \rightarrow e \qquad P_2 : e}{C : H}$$

Affirming the consequent **invalid** = Confirmation

Assignment One (1.d) asks about "abductive reasoning". This topic has not been adressed in this lecture (but it has been addressed in the tutorial).

Nevertheless, some information can already be found in Ladyman, p 47. "Inference to the best explanation", which is sometimes called abduction (or an abductive argument), is the mode of reasoning, that we employ when we infer something on the grounds that it is the best explanation of the facts (and theories) we already know. Etc.

For instance, the best explanation, H, for the event, *e*, "that the streets are wet", is "that it has been raining". In other words, "It has been raining", H, is the best explanation for the event "that the streets are wet", e. Abductive reasoning involves both inductive reasoning (for instance, most of the times that the streets are wet, this is caused by rain – rather than by the cleaning-car of the public works, or all kind of other implausible explanations. It also involves deductive reasoning, making use of the true sentence that "If it rains, then, the streets get wet." But, the logical form would then be 'Affirming the consequent', which is invalid (see schema, and first read P_2, than P_1).

The plausibility of an explanation usually is based on coherency with other facts, or consistency with more general theories.

Another example. The best explanation, H, for the event, e, that some people get cured by homeopathic medicines is the placebo effect (whatever that may be), rather than its chemical working. The latter is based on deductive reasoning: we assume that illnesses are caused and cured by something chemical. However, homeopatic medicines cannot have enough chemicals to cause this effect. In brief, we deny that P_1: *H* (the working of homeopatic medicine) implies *e* (getting curred by homeopatic medicine) is true. In other words, we believe that the propositions $H \rightarrow e$ is false.

Also think of Feynman, who stressed that our guesses (= explanations H of event e) are *plausible or implausible*. We assess the plausibility of a guess by means of coherency and consistence with relevant background knowledge.